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1. Your reference	26.0187 GB NP	
2. Patent application number *(The Patent Office will fill in this part)*	9923870.1	-9 OCT 1999
3. Full name, address and postcode of the or of each applicant *(underline all surnames)*	Schlumberger Limited 5 Julianaplein Curacao Netherlands Antilles	
Patents ADP number *(if you know it)*	4189312004	
If the applicant is a corporate body, give the country/state of its incorporation	Netherlands Antilles	
4. Title of the invention	Methods and Apparatus for Making Measurements on Fluids Produced from Underground Formations	
5. Name of your agent *(if you have one)*	WANG, William L.	
"Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*	c/o Schlumberger Cambridge Research Ltd High Cross, Madingley Road Cambridge CB3 0EL	
Patents ADP number *(if you know it)*	7620616001	

6. If you are declaring priority from one or more earlier patent applications, give the country and the date of filing of the or of each of these earlier applications and *(if you know it)* the or each application number	Country	Priority application number *(if you know it)*	Date of filing *(day / month / year)*

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8. Is a statement of inventorship and of right to grant of a patent required in support of this request? *(Answer 'Yes' if:* YES

a) any applicant named in part 3 is not an inventor, or
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Description	8
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Abstract	1
Drawing(s)	3 + 3

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Priority documents	–
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Statement of inventorship and right to grant of a patent *(Patents Form 7/77)*	–
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Request for substantive examination *(Patents Form 10/77)*	–
Any other documents *(please specify)*	–

11. I/We request the grant of a patent on the basis of this application.

Signature [signature] Date 8 October 1999

12. Name and daytime telephone number of person to contact in the United Kingdom WANG, William L. 01223-325268

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METHODS AND APPARATUS FOR MAKING MEASUREMENTS ON FLUIDS PRODUCED FROM UNDERGOUND FORMATIONS

FIELD OF THE INVENTION

The present invention relates to methods and apparatus for making measurements on fluids produced from underground formations into a borehole, such as are found in hydrocarbon producing wells. In particular, the invention relates to methods and apparatus applicable to situations in which fluids may be produced from more than one location or interval in the borehole.

BACKGROUND OF THE INVENTION

A typical hydrocarbon production well W is shown schematically in Figure 1 (while shown vertical, it will be appreciated that the well can deviate from vertical and may in certain portions be substantially horizontal). The formations surrounding the well will typically have a number of (vertically) spaced permeable zones P_1, P_2 from which fluids (water, oil and/or gas) are produced, separated by relatively impermeable zones I_1, I_2, I_3. Where the formation fluid pressure is sufficiently high, the fluids will pass from the formation into the well and up to the surface for collection. However, in many cases, formation pressure is insufficient to force the fluids to the surface and some assistance must be provided, often in the form of a pump (e.g. an electric submersible pump or "ESP" located in the well itself provided with power from the surface). Since more than one zone in a well might be producing useful fluids, it is often desirable to co-mingle fluids from all of the zones into a single stream in order to maximise production from that well. However, if the zones have significantly dissimilar flow characteristics (pressure, flow rate, water/oil ratio, etc.) it is possible to get cross-flow in which the fluids produced from one zone pass out of the borehole and into the formation of another zone such that fluids produced form the first zone are lost and production from the second zone is inhibited. Consequently, before a decision is taken to produce from multiple zones, it is desirable to determine the flow characteristics of each zone, especially in wells where production is relatively low.

A number of tools and techniques have been proposed for evaluating the production characteristics of zones in wells. For example, the MDT Modular Formation Dynamics Tester tool of Schlumberger allows individual zones to be tested in a well. Figure 2 shows a

schematic view of the MDT in PVT sampling configuration. The tool 10 is lowered into the well 12 on wireline cable 14 which provides power and communication with the surface unit 16. The tool includes an electric power module18, a hydraulic power module 20, a probe module 22, an Optical Fluid Analyser (OFA) module 24, a multisample module 26 and a pumpout module 28. In use, a probe 30 in the probe module 22 is extended to contact the formation 32 and is connected to a flow conduit 34. Fluid is drawn from the formation 32 through the probe module 22 where pressure measurements can be made and into the conduit 34 by the action of the pumpout module 28. The fluid passes into the OFA module 24 where optical absorption measurements in the visible and infra-red region allow fluid discrimination and quantification, and changes in the index of refraction allow free gas detection. Individual samples of fluids can be stored in the multisample module 26 from different locations in the well for analysis at the surface. One or more packer modules (not shown) can also be included if it is desired to isolate an interval of the well during testing. While the MDT has many advantages, the size of the probe, pump and sample chambers means that it is not possible to sample the formation at its natural flow rate or even at its potential maximum flow.

US 5,337,821 discloses a formation testing tool which attempts to overcome the problems associated with probe-type tools by providing a pair of packers to isolate an interval of the well and a downhole pump which is used both to set the packers and to withdraw fluids from the formation into the tool where measurements are made or properties such as pressure, temperature and resistivity. The basic measurement approach in this case is similar to that of the MDT described above.

Other tools and methods for formation sampling and testing can be found in US 4,535,843, US 4,860,580, US 4,513,612 and US 4,936,139.

Another form of test which can be used to test low flow wells in their normal producing state is the swab test which is illustrated in Figure 3. In the swab test tubing 38 is set to the assumed level 40 of the zone of interest which is isolated from the rest of the well by cup packers 42. The formation fluids F are allowed to flow into the tubing 38 and reach the height H determined by the hydrostatic pressure of the formation. Swab cups 44 are then lowered through the tubing 38 on slickline 46 until the cups sit in the fluids F. The swab cups 44 are

then drawn back up the well taking the fluid above with them and drawing more fluid from the zone below. This is repeated until sufficient fluid is drawn above the cups to be extracted at the surface and analysed. This measurement does allow some estimate to be obtained for productivity index and water cut but otherwise is very limited and has low accuracy. It is not possible to place the cup packers accurately and so the zone of interest might be missed. Also, it is necessary to have at least a workover rig present in order to run the tubing in the well.

In wells which produce fluids to the surface naturally, it is possible to merely place a production logging tool in the flowing fluids and make measurements. However, this is clearly not possible for wells which do not naturally produce to the surface so other approaches are required.

It is an object of the present invention to provide methods and apparatus which can be run using wireline conveyance techniques and which allow measurements to be made on fluids at something approaching natural flow rates for the formation in question.

SUMMARY OF THE INVENTION

A method according to the present invention comprises isolating an interval of the borehole from the rest of the borehole; drawing fluid from the formation through the isolated interval and into a flow passage at a rate close to normal for that formation, and measuring parameters of the formation fluids flowing through the flow passage.

Apparatus according to the invention comprises a tool body with a flow passage, packers mounted on the tool body for isolating an interval of the borehole, a pump for drawing fluid from the formation in the interval and through the flow passage at rates close to normal production rates for that formation, and a suite of one or more sensors for measuring the fluids as they pass through the flow passage.

By providing the flowing fluids in a flow passage, it is possible to make measurements on the flowing fluids which are directly comparable with such measurements made in non-pumped flows. Thus the present invention provides a system for making measurements on low flow

intervals which can be compared to those in higher flows without the need for complex interpretation of measurements.

Downhole samples can be taked and can be used to validate the interpretation as well as provide current PVT information in the field life.

The packers are preferably inflatable packers. Inflation of the packers can be achieved by a separate supply of an inflating fluid, such as nitrogen gas, or by using a suitable pump and valve mechanism downhole. Cup packers or any other form of device which allows the interval to be isolated from the remainder of the well can also be used. Each of these will be activated in the appropriate manner.

The pump is required to draw fluids at close to normal production rates for the interval in question. Therefore a relatively high capacity pump is required. Electric submersible pumps are particularly preferred. Since the power requirement of an ESP can be relatively high, it may be preferable to provide a separate cable for electric power to the ESP in order that it can run at the appropriate rate. The pump can be arranged to discharge the withdrawn fluids into the borehole outside the isolated interval. Once the packers are released, the withdrawn fluids will return to the formation until the normal formation hydrostatic pressure is balanced. It will be appreciated that the invention is not restricted to ESPs, but can include any suitable downhole pump.

The measurement suite can be provided by placing a production logging tool in the tool body and making measurements on the fluid drawing from the interval by the pump. Typical measurement are oil bubble count, water holdup, oil, water and gas flow rates, pressure, and temperature. It is also desirable to include a formation gamma ray measurement in order to allow accurate depth placement of the tool. Transient testing such as skin and Kh are also possible. Downhole samples for PVT analysis can be captured as well across each of the zones being tested. The tool or sonde is typically placed below the pump. Furthermore, a pressure sensor can be provided above the pump to provide an indication of the fluid level above the pump. This can be useful to know when fluids will be produced at the surface or give an indication of the amount of fluid entering other zones of the formation above the test interval.

The preferred method of conveying the tool to the level of interest in the borehole is via wireline cable. Other cables may be required to provide power for the ESP or pressurising fluid for the packers. These various cables can be bundled together into a single jacketed umbilical with electrical cabling and a pressure rated conduit for fluids. although other techniques such as coiled tubing or tubing conveyance could be used according to requirements.

A further aspect of the invention has the downhole pump used to inject fluids into the formation, essentially operating in reverse of that described above. In this case, the source of the fluids can be the well itself, or specific fluid supplied from the surface as required. The ability to reverse the pump and running the system as an injectivity tester can be useful in well where the pressures in the various zones are quite different.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 shows a borehole in a formation having several producing zones;
Figure 2 shows a prior art formation testing tool;
Figure 3 shows element of a swab test;
Figure 4 shows a schematic view of one embodiment of the invention;
Figure 5 shows a first sensor package for use in the tool of Figure4;
Figure 6 shows a second sensor package for use in the tool of Figure 4; and
Figure 7 shows an alternative embodiment of the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

One embodiment of a tool according to the invention is shown in Figure 4 and comprises generally a tubular tool body 50, packers 60, a pump 70 and a sensor package80.

The tool body 50 is formed from a tubing joint 52 having a perforated pup joint 54 connected thereto and a central passage 56 closed at its lower end 58.

Inflatable cup packers 62, 64 are mounted on the outside of the tool body 50, spaced on either side of the perforations 55 in the pup joint 54 so as to define an isolation interval when inflated in the borehole. The spacing of the packers 62, 64 can be set at the surface according

to the assumed extent of the zone of the formation to be tested. If it is desired to make test in a borehole with zones of substantially different extent, an alternative arrangement includes a slip joint in the tool body between the packers as is shown in Figure 7. This allows the spacing to be set downhole as will be explained in further detail below. The packers 62, 64 are inflated using pressurised nitrogen gas which is supplied from the surface via a supply line 66. Appropriate valve controls allow selective inflation and deflation of one or other packer. A weak point 68 is provided in the supply line 66 to allow it to be detached should the tool become stuck in the borehole. An alternative to using nitrogen to inflate the packers is to provide a pump which pumps borehole fluids to the packers to inflate them and has a choke to release fluids. This can be connected to the same engine as the main pump such that when the main pump is run, fluid is pumped continuously to the packers and the choke continuously vents the fluid to the borehole while maintaining pressure in the packers. Thus when the main pump operates, the packers set (fluid is pumped into the packer at a greater rate than it leaves through the choke), and when it stops, the packers release (fluid in the packers vents through the choke).

An ESP 72 is located at the other end of the tool body 50 and is arranged to draw fluid through the perforations 55 and along the central passage 56 of the tool. This fluid is then vented from the top of the tool. The rating of the pump 72 should be close to the maximum producing rate of the zone to be tested. While this rate might not be known accurately, it can be estimated prior to the test by other measurements. Since ESPs are commonly found in oilfield applications, for reasons of cost, it is desirable to use a commercially available ESP if possible. However, the action of the ESP in this case is inverted compared to that normally found so it may be necessary to modify the pump in order to work effectively in that configuration. Such modifications are known. Also, there are commercially available pumps which work in an inverted configuration. The pump can be a fixed rate pump or can use a variable speed drive (VSD) which allows several flow rates to be tested, either on each zone, or for different zones. Power is supplied to the ESP 72 from the surface via a separate power cable 74 which connects to the ESP 72 at a weak point 75 which allows disconnection if the tool becomes stuck in the borehole. A fishing head 76 is provided at the top of the motor to allow connection to a wireline cable 78, again with a weak point 79 for emergency disconnection. From the fishing head 76, a wireline cable connection 77 feeds around the ESP 72 and into the tool body 50 for connection to the sensor package 80.

Located within the tool body 50 between the perforations 55 and the ESP 72 is a sensor package 80 for making measurements on the formation fluid drawn through the tool by the ESP. Since the fluids are behaving much as produced fluids, production logging sensors can be used directly. The particularly preferred approach is to mount a production logging tool inside the tool body and make standard measurement when the ESP is drawing fluids from the formation. Suitable production logging tools comprise the PS Production Services Platform (PSP), or the FloView tool, both of which are available from Schlumberger. The PSP tool is shown in Figure 5 and comprises a basic measurement sonde 82 which connects to the wireline feedthrough 77, a gradiomanometer sonde 84 and a flow-caliper imaging tool 86. An optional pressure gauge carrier sonde 88 can also be present between the basic measurement sonde 82 and the gradiomanomenter sonde 84. The PSP tool can make the following measurements: pressure, temperature, fluid density, flow rate, water holdup, bubble count and relative bearing. A gamma ray detector can be connected to the tool as well in order to measure natural formation gamma ray activity. The FloView tool is shown in Figure 6 and comprises an electronics section 90 which includes a relative bearing measurement and a probe section 92 carrying four resistive probes in an arm and blade arrangement. This tool makes water holdup, oil holdup and bubble count measurements. Again a gamma ray detector can be included as with the PSP. Other measurements can include fluid resistivity, and optical reflectivity and transmissivity. Tool power, instruction and data signals travel over the wireline cable, independently of the power supply to the ESP or the nitrogen supply to the packers. As the tool is positioned in the flow passage defined by the tool body, the measurements it makes are fundamentally the same as it would make when used in a normal production logging application. Thus it is possible to use the same basic measurement tool in both high and low flow regions with direct comparison of the results, ~~something that has not been possible prior to this invention.~~

It will be appreciated that a suitable tool for use in the present invention is not limited to those listed above and could include other functionalities such as downhole memory gauges, other production logging tools, other formation evaluation tools, etc.

In use, the tool is deployed in a borehole in the conventional manner with surface equipment. The wireline cable, pump power cable and nitrogen supply line are run from separate spools

at the surface and temporarily connected together before they are run into the well, the wireline cable providing mechanical support to the other cables and to the tool. The tool is run to the desired depth and accurate location of the tool is achieved using the gamma ray sensor which can be compared to earlier gamma ray logs to locate the zone of interest. At this point, the packers are set by supplying nitrogen gas until an appropriate sealing pressure is achieved. The ESP is then operated to draw fluids from the formation into the tool at a rate which is close to the maximum production rate of that zone. The fluids are drawn through the tool past the sensor package which makes measurements according to the particular sensors present and transmits the data to the surface via the wireline cable. Because the fluids are being drawn from the formation at close to the maximum rate, the measurements can be considered representative and do not need substantial correction on interpretation. In the case where the maximum flow rate is not well estimated, it might be appropriate to make measurements at a number of different pump rates using a VSD as described above. Fluids from the formation leave the tool at the top and pass into the borehole above the upper packer. When the packer are released, the fluids will flow back into the formation until hydrostatic balance is achieved.

In the embodiment of Figure7, in which a slip joint 94 is positioned between the packers 62', 64', deployment is slightly different. The tool is run into the borehole as before until the correct depth is reached. At this point, the slip joint is fully extended. The lower packer 64' is then inflated just below the bottom of the zone to be tested. The tool is then lowered until the upper packer 62' is just above the top of the zone to be tested and this is then set also. There are a number of ways to achieve the sequential setting of the packers. Two control lines to the nitrogen supply can be used which allows completely independent operation of the packers. Alternatively, a pressure regulator can be provided in the upper packer which always causes the lower packer to set before the upper. Another alternative when pressurising the packers using a downhole pump, is active control of the setting of each packer using electronic control.

The description above considers the case in which wireline conveyance is used. The invention is not limited to this and can be conveyed using tubing or coiled tubing according to conditions such as hole deviation.

CLAIMS

1 Apparatus for making measurements on fluids produced into a borehole from an underground formation, comprising:

i) a tool body with a flow passage;

ii) packers mounted on the tool body for isolating an interval of the borehole;

iii) a pump for drawing fluid from the formation in the interval and through the flow passage at rates close to normal production rates for that formation; and

iv) and a sonde carrying one or more sensors located in the flow passage for making measurements on the fluids as they pass through the flow passage.

2 Apparatus as claimed in claim 1, comprising a pair of packer spaced apart on the tool body on either side of perforations allowing fluid communication between the borehole and the flow passage.

3 Apparatus as claimed in claim 2, wherein the tool body includes a slip joint positioned between the packers which allows the overall length of the tool body between the packers to be varied.

4 Apparatus as claimed in claim 1, 2 or 3, wherein the packer comprise inflatable packers which are inflated using pressurised fluid provided from the surface, or by borehole fluid provided by a pump downhole.

5 Apparatus as claimed in any of claim 1 to 4, wherein the pump comprises an electric pump mounted at one end of the tool body and having a fixed or variable pumping rate.

6 Apparatus as claimed in any preceding claim, wherein the sonde includes sensors for measuring one or more of the following parameters: oil bubble count, water holdup, oil flow rate, water flow rate, gas flow rate, pressure, temperature and formation gamma ray emission.

7 Apparatus as claimed in any preceding claim, further including means for taking samples of the fluids.

8 A method of making measurements on fluids produced from underground formations surrounding a borehole, comprising:

i) isolating an interval of the borehole;

ii) drawing fluid from the formation around the interval through the interval at a rate close to the maximum production rate for that formation;

iii) directing the fluid through a flow passage; and

iv) measuring parameters of the flowing fluid as it is directed through the flow passage.

9 A method as claimed in claim 8, wherein the step of isolating the interval comprises positioning a tool in the borehole having a pair of packers spaced apart thereon, and inflating the packers so as to seal with the borehole and define the interval between them.

10 A method as claimed in claim 9, wherein the length of the tool body between the packers is adjustable, the isolating step comprising positioning the tool in the borehole, setting the lowest packer, adjusting the length of the tool body and setting the uper packer.

11 A method as claimed in claim 9 or 10, wherein the fluid is drawn through the tool using a downhole pump.

12 A method as claimed in claim 11, wherein the pump discharges fluid drawn through the interval into the borehole outside the interval.

13 A method as claimed in any of claims 8 to 12, wherein the measured parameters include at least one of oil bubble count, water holdup, oil flow rate, water flow rate, gas flow rate, pressure, temperature ,formation gamma ray emission, skin and Kh.

14 A method as claimed in claim 13, wherein formation gamma ray emission is measured and used to determine the depth of the tool in the borehole.

15 A method as claimed in any of claims 8 to 13, wherein the method is performed by a tool conveyed into the well by means of wireline cable, coiled tubing or other tubing.

15 A method as claimed in any of claims 8 to 15, further comprising taking samples of the fluids drawn from the formation into the interval.

ABSTRACT

Methods for making measurements on fluid produced from a formation into a borehole include the steps of isolating an interval of the borehole from the rest of the borehole; drawing fluid from the formation through the isolated interval at a rate close to normal for that formation, and measuring parameters of the formation fluids flowing through the isolated interval Apparatus for performing such methods have a tool body with a flow passage, packers mounted on the tool body for isolating an interval of the borehole, a pump for drawing fluid from the formation in the interval and through the flow passage at rates close to normal production rates for that formation, and a suite of one or more sensors for measuring the fluids as they pass through the flow passage.

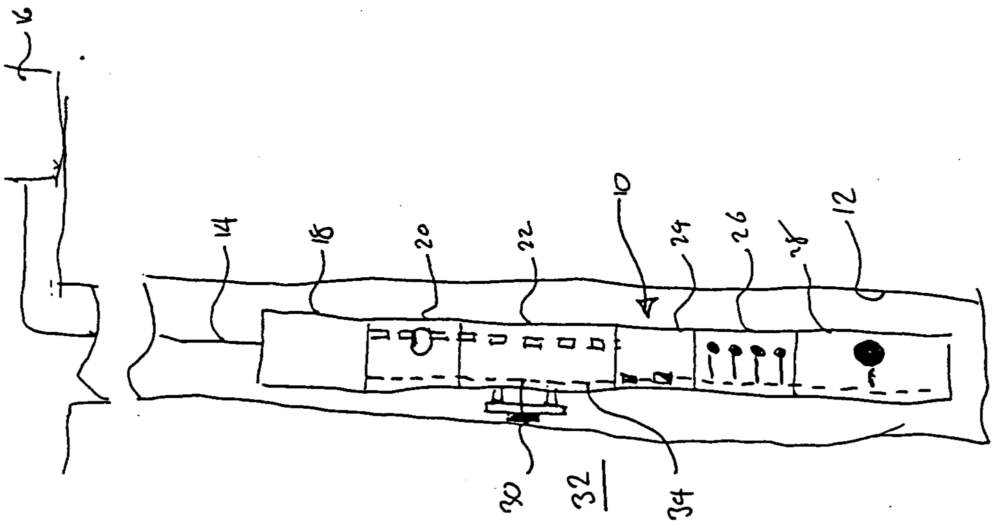

Figure 2

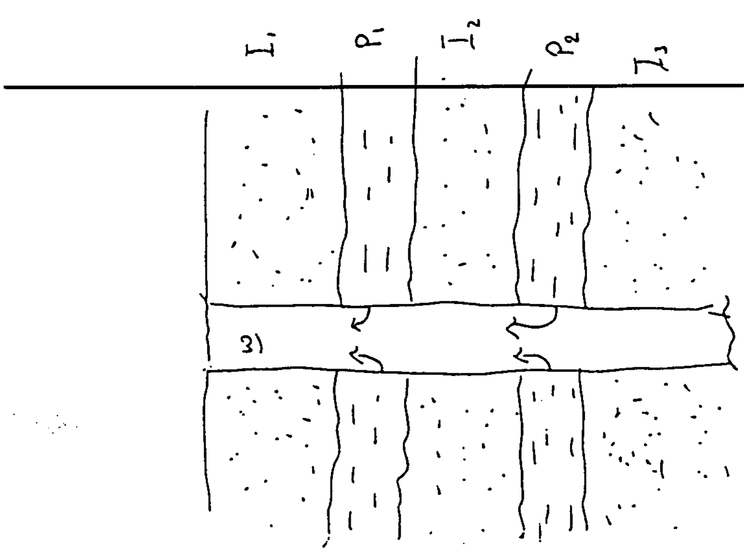

Figure 1

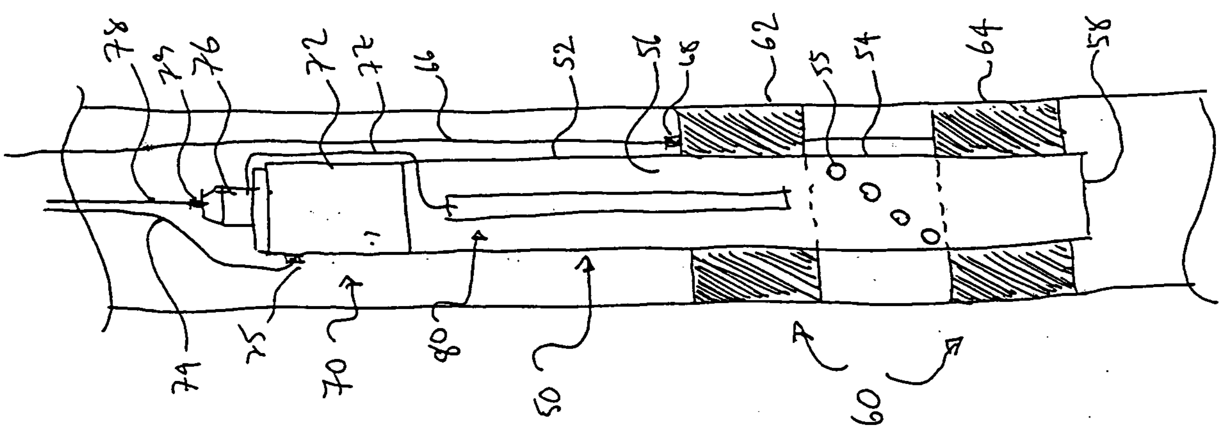

Figure 4

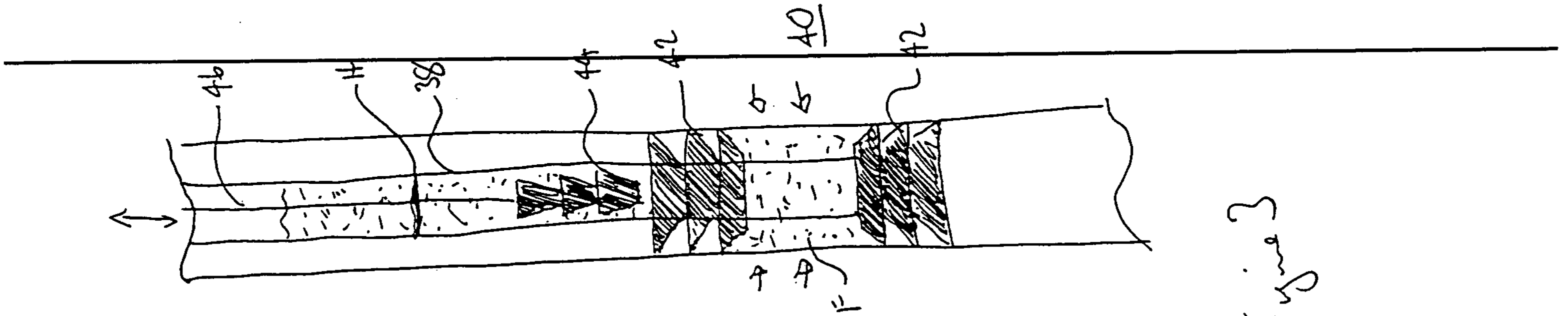

Figure 3

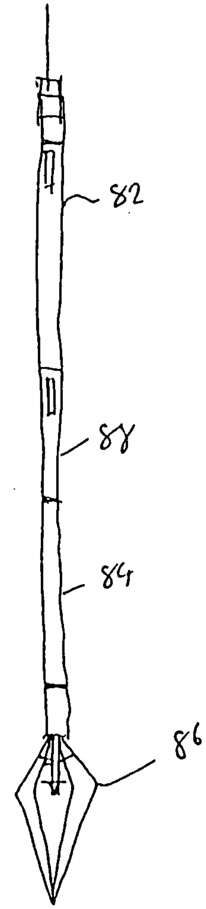

Figure 5

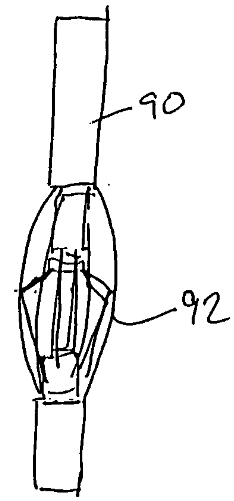

Figure 6

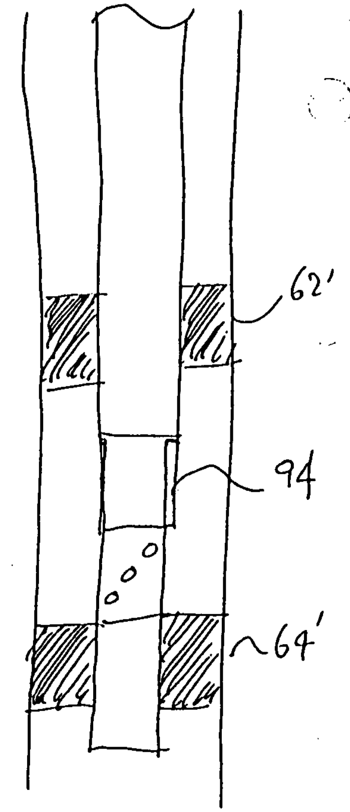

Figure 7